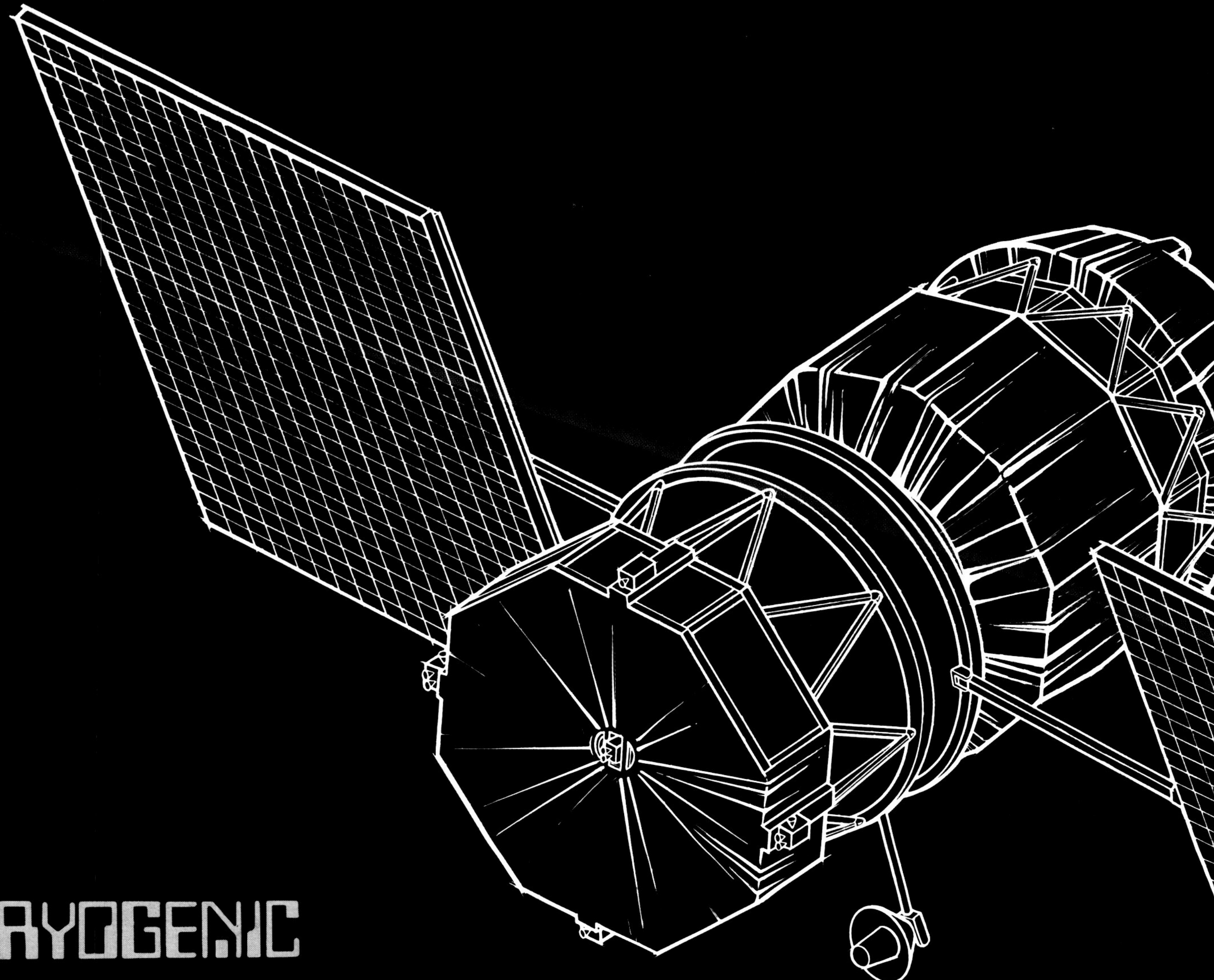
# COLD-SAT



CRYOGENIC
ON-ORBIT
LIQUID
DEPOT—
STORAGE,
ACQUISITION,
TRANSFER

(NASA-TM-102308) COLD-SAT: CRYOGENIC ON-ORBIT LIQUID DEPOT-STORAGE, ACQUISITION AND TRANSFER (NASA. Lewis Research Center) 14 p CSCL 22A
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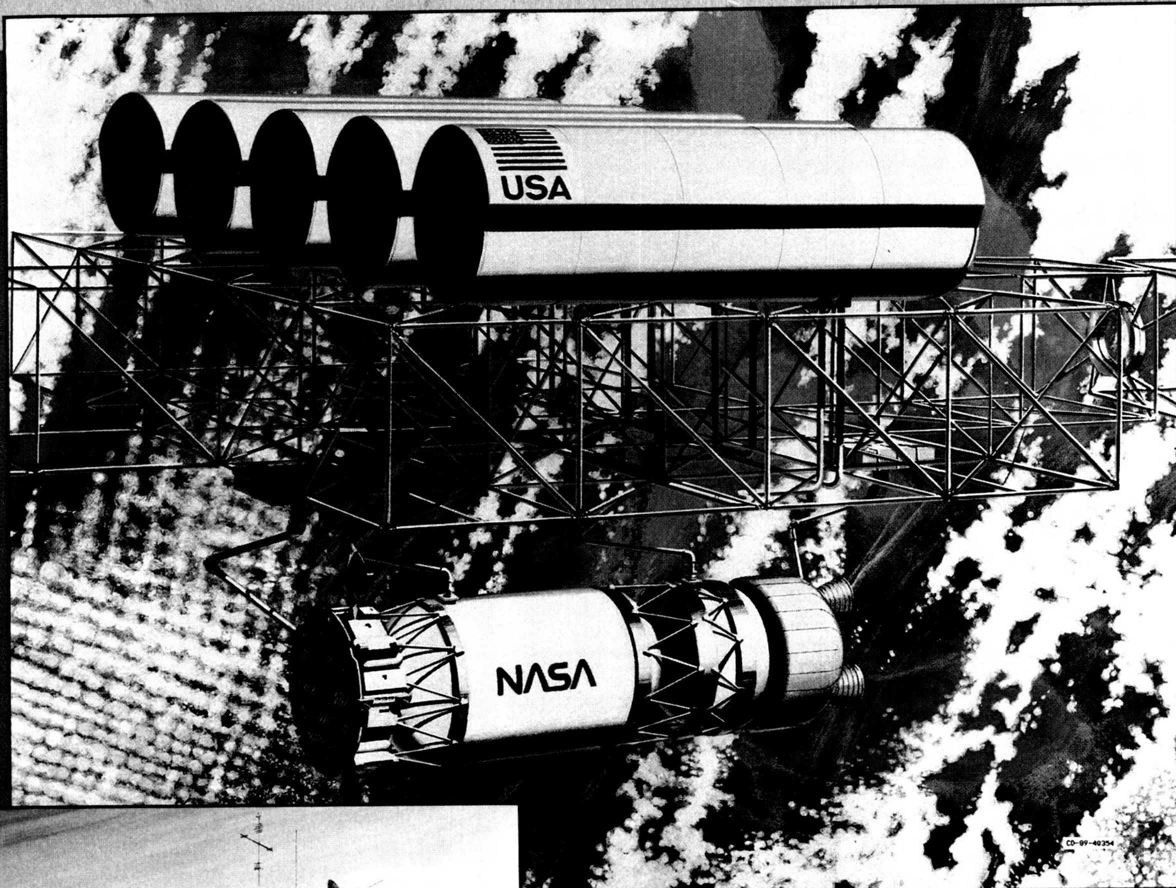
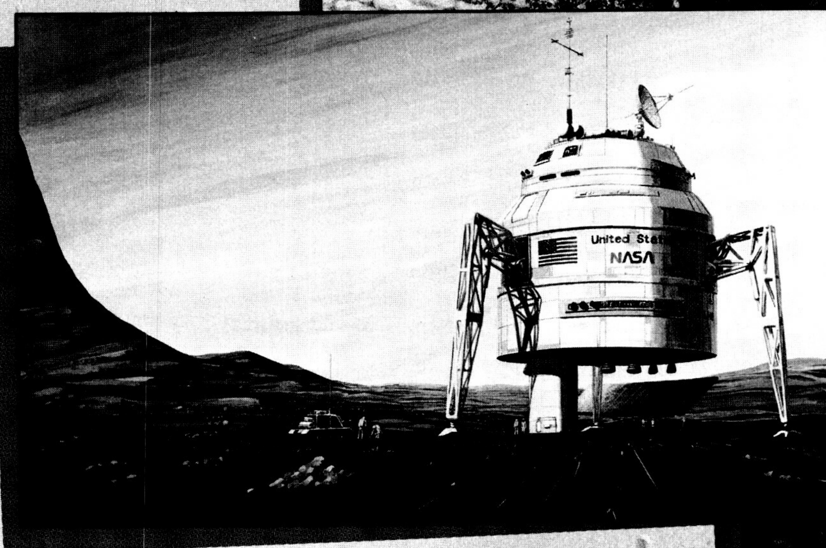
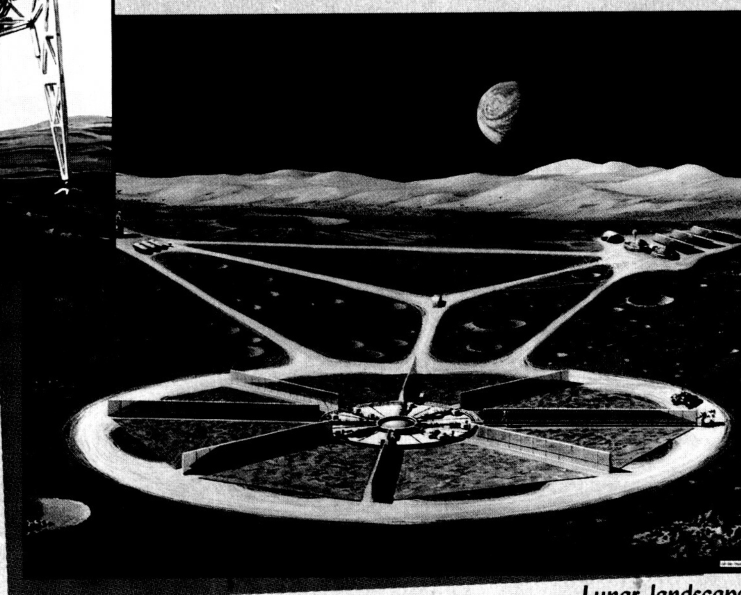
*On-orbit refueling and servicing facility for space transfer vehicles*




*Manned exploration of Mars*





*Lunar landscape of the 21st century*

As we move into the next century, NASA is entering an era of expanded space activity. Space-based transportation systems will carry cargo and humans from low-earth orbit to geosynchronous orbit, to lunar bases, and to the martian surface. Support of these future missions will require new, long-lived, on-orbit systems using subcritical cryogens for propellants and life-support systems. Such on-orbit systems present low-gravity fluid management challenges of long-term storage and efficient fluid transfer and supply techniques. Development of these cryogenic systems requires on-orbit experimentation to demonstrate the capability of performing these fluid management tasks and to obtain the engineering data base required to correlate analytical tools used for system design.

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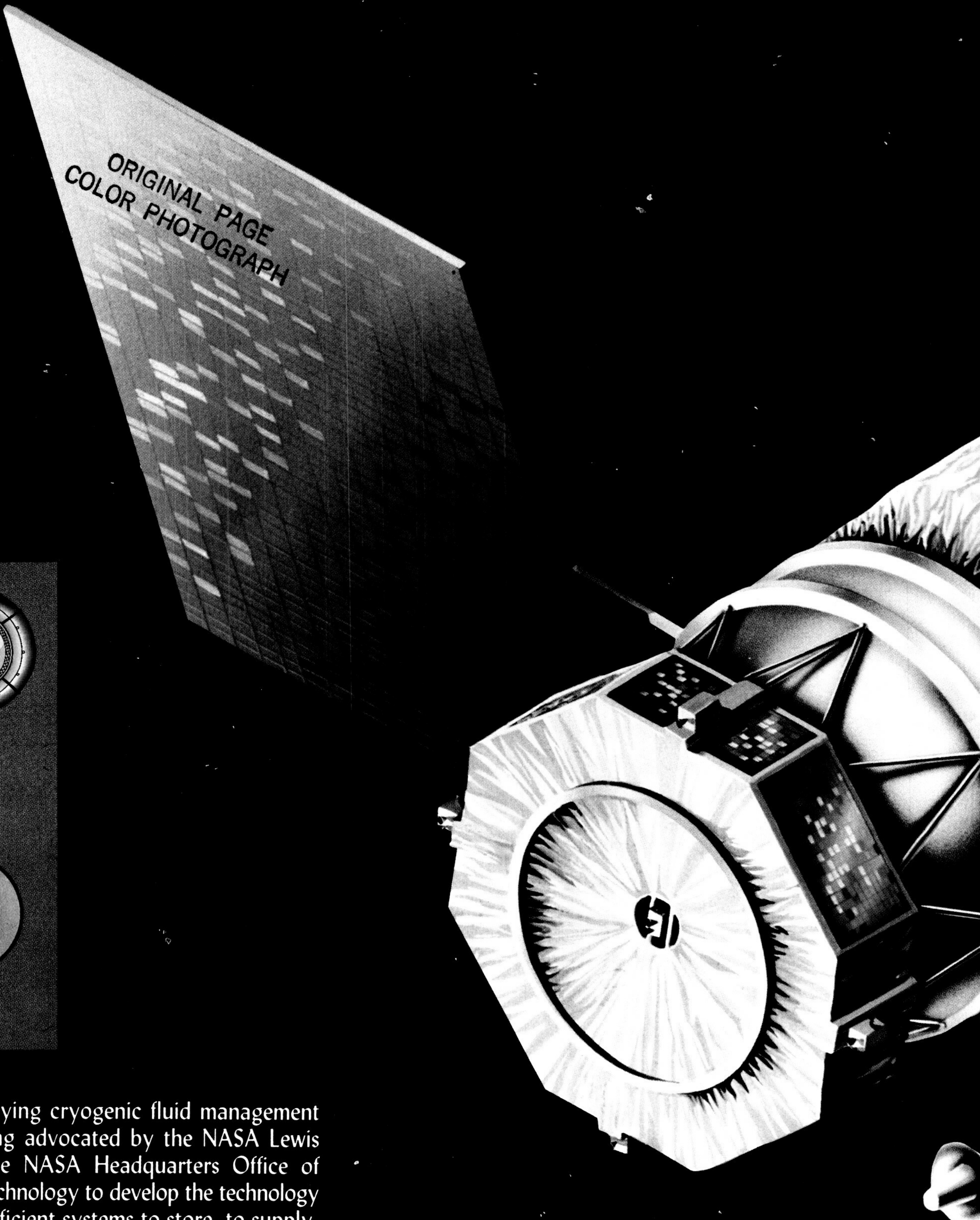
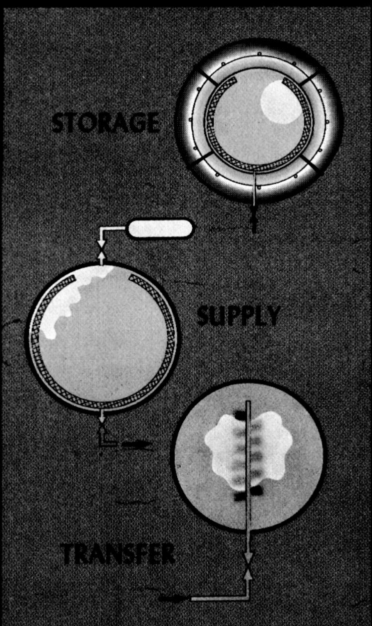


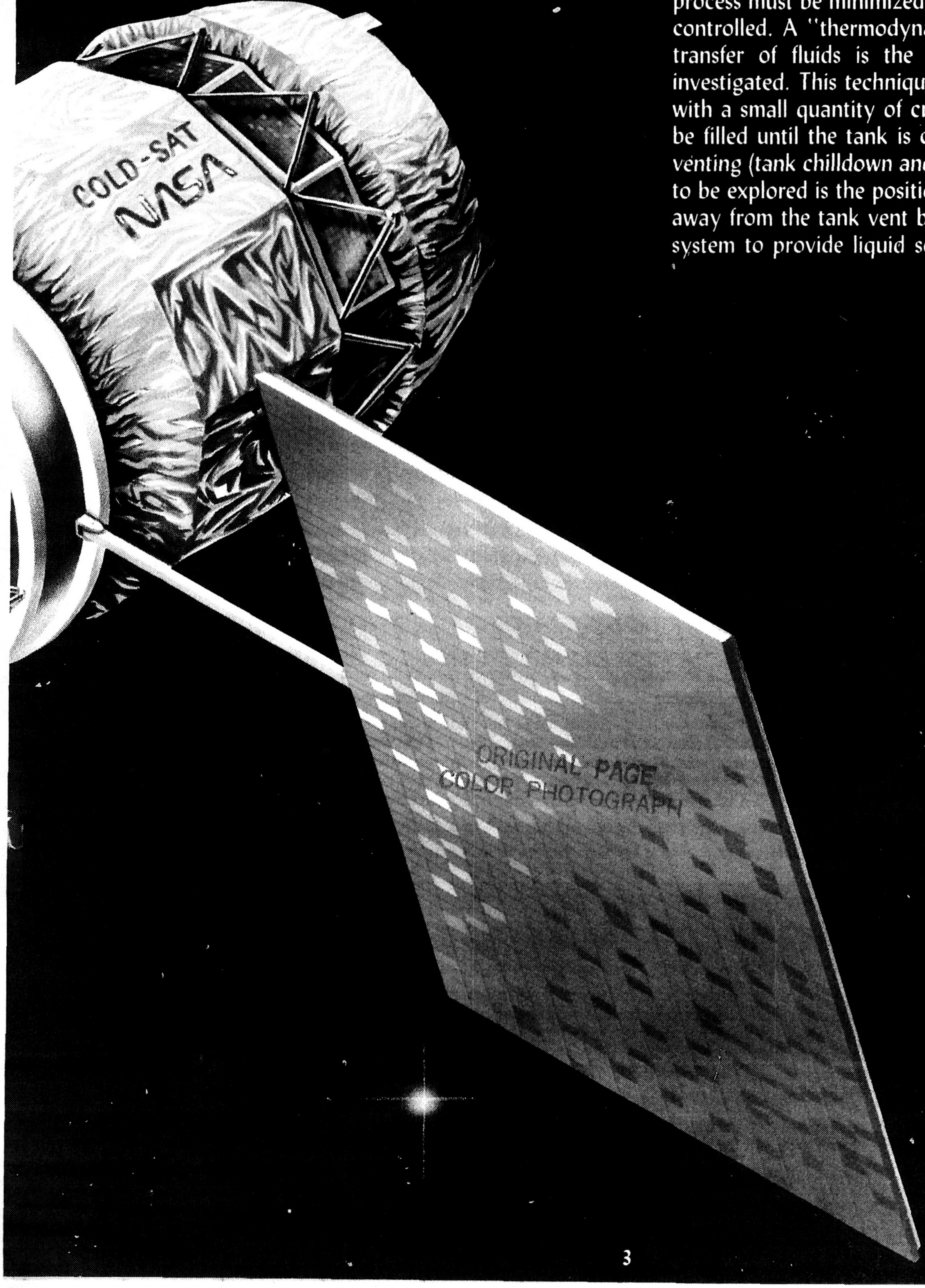

COLD-SAT, a free-flying cryogenic fluid management flight experiment, is being advocated by the NASA Lewis Research Center and the NASA Headquarters Office of Aeronautics and Space Technology to develop the technology to enable the design of efficient systems to store, to supply, and to transfer subcritical cryogenic fluids in the low gravity of space.

General technology areas to be investigated by the COLD-SAT experimentation are the following:

**LIQUID STORAGE**—Requirements exist to store cryogenic liquids in the low-gravity space environment for periods of several hours to perhaps several years while minimizing liquid boiloff and controlling tank pressure. Minimizing liquid boiloff generally requires very efficient tank thermal insulation systems, and controlling tank pressure may require liquid mixing and thermodynamic vent systems.

**LIQUID SUPPLY**—Requirements exist to feed single-phase cryogenic liquids from a tank in the low-gravity environment of space. The absence of gravity makes this task difficult, because gravity would normally position the dense fluid (liquid) at the tank "bottom" and the lighter fluid (vapor) at the tank "top." This technology area typically involves studies of continuously supplying single-phase liquid to the tank outlet and pressurization gas requirements during expulsion of liquid from the tank. Preferred techniques for liquid acquisition use fine mesh screen materials as capillary devices. However, the effectiveness of such techniques with cryogenic liquids in space remains unproven. Pressurization techniques for discharging cryogens from propellant tanks were developed for rocket vehicles with high expulsion rates and have not been characterized for the low expulsion rates anticipated for low-gravity transfer operations.

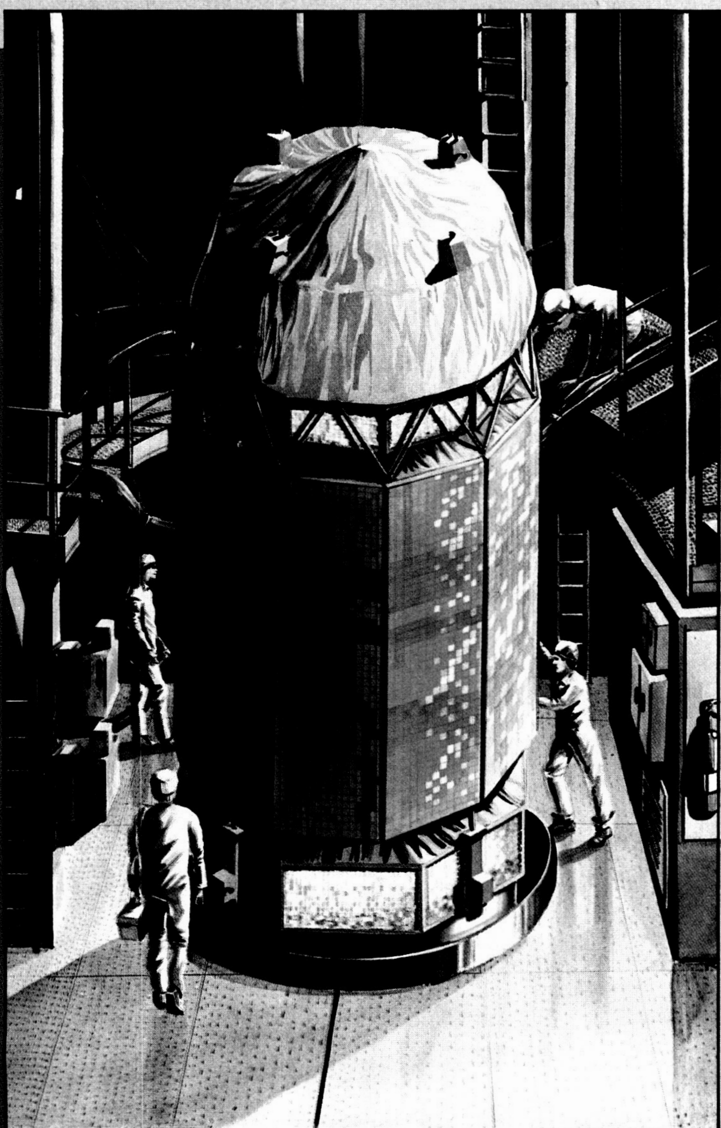
**FLUID TRANSFER**—Requirements exist to transfer cyrogenic liquids from one tank to another in the low-gravity environment of space. Fluid losses associated with the transfer process must be minimized, and the tank pressures must be controlled. A "thermodynamic" technique for low-gravity transfer of fluids is the recommended approach to be investigated. This technique consists of alternately chilling, with a small quantity of cryogen, and venting the tank to be filled until the tank is cold enough to be filled without venting (tank chilldown and no-vent fill). Another approach to be explored is the positioning of the accumulating liquid away from the tank vent by use of a low-thrust propulsive system to provide liquid settling.



**FLUID HANDLING**—A need exists to develop the technology associated with fluid slosh dynamics and slosh control. Liquid motion which may result from spacecraft docking and separation maneuvers or thruster firings has not been well characterized. For many space systems (e.g., cryogenic fluid depots, space transfer vehicles, etc.), the contained liquid mass is a very large percentage of the total mass of the system. For these applications, liquid slosh dynamics in the low-gravity environment of space must be better understood to permit safe and controlled operations. Additionally, space missions which are aborted may require that the spacecraft cryogenic liquids be dumped to space or returned to a storage tank. The thermodynamic and fluid dynamic processes associated with the in-space dumping of cryogenic tankage are not well understood.

**ADVANCED INSTRUMENTATION**—A need exists for instrumentation to determine the quantity (or mass) of liquid in a tank under low-gravity conditions, to measure the liquid mass flow rates while determining the onset of two-phase flow, and to assess the occurrence and magnitude of leaks in cryogenic systems.

**The technologies associated with low-gravity cryogenic liquid storage and fluid transfer have been identified as enabling for future NASA and Department of Defense space missions.**



*Final checkout of COLD-SAT in the launch pad clean room*

During the 1990's, the COLD-SAT spacecraft will be inserted into a low earth orbit by an expendable launch vehicle from one of the launch complexes located at the Cape Canaveral Air Force Station in Florida.

Cryogenic hydrogen, the logical propellant choice for near-earth operation and space exploration, will serve as the test fluid on board the COLD-SAT spacecraft. The duration of the mission is expected to be between 6 and 12 months, depending on the test scenario.

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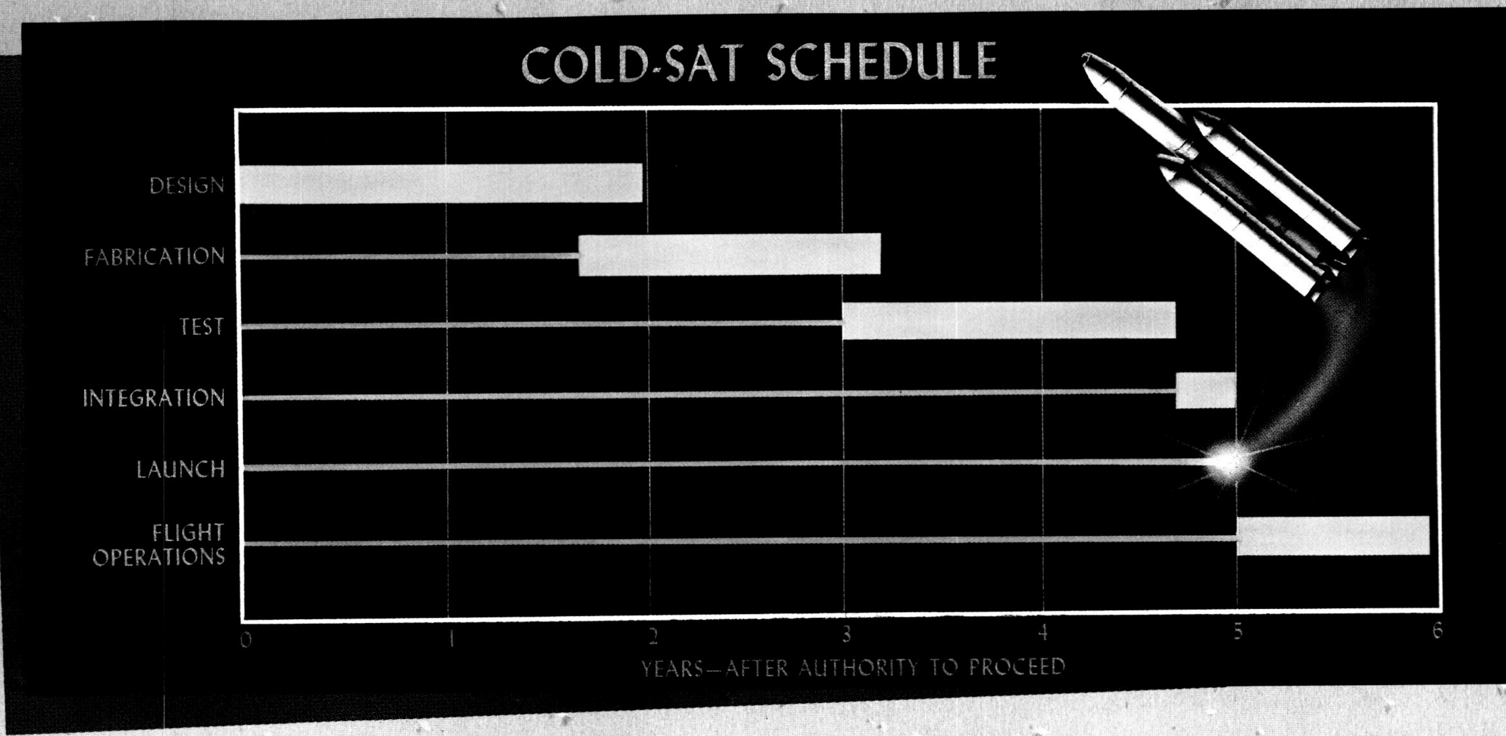


Why in-space experimentation? At the Cryogenic Fluid Management Technology Workshop held in 1987 at the NASA Lewis Research Center, consensus among the over 100 attendees from government, industry, and academia reconfirmed that the development of cryogenic fluid management technologies would require in-space experimentation. Ground-based test facilities, including drop towers and aircraft, cannot provide a complete engineering data base because of constraints on experiment size, test fluid, and low-gravity duration. From this workshop, the COLD-SAT concept evolved.

Why liquid hydrogen testing? On the basis of several studies, liquid hydrogen has been selected as the prominent cryogenic propellant for most future NASA and Department of Defense space missions. COLD-SAT experiments with liquid hydrogen will provide the data base to support the design of systems for these future space missions. Handling of liquid hydrogen in space presents challenging fluid management problems because of its low temperature, low density, and small surface tension forces. COLD-SAT will afford an opportunity to demonstrate the ability to store, to supply, and to transfer in space this difficult cryogenic liquid successfully. Further, development of fluid management technology with liquid hydrogen permits application of the results to other cryogenic fluids of interest, such as oxygen and nitrogen, whereas testing with other fluids would not allow predictions of liquid hydrogen system performance.

Why an expendable launch vehicle? The United States entry to space is via either the space transportation system (Space Shuttle) or an expendable launch vehicle. Liquid hydrogen experimentation on board the Space Shuttle would (1) present a potentially catastrophic hazard to the crew and the Shuttle, (2) require the installation of a very costly hydrogen vent system, and (3) provide less technology return because the Shuttle's maximum flight time of seven days results in a limited test matrix.

Experimentation on board the Space Shuttle with a nonhazardous cryogenic fluid is not cost effective because (1) the short flight time of the Shuttle and hardware limitations would require multiple missions to develop the necessary technologies and (2) the technologies could not be developed to the same level of confidence. The desired high reliability for the single expendable launch vehicle mission was considered in the cost estimates for COLD-SAT.

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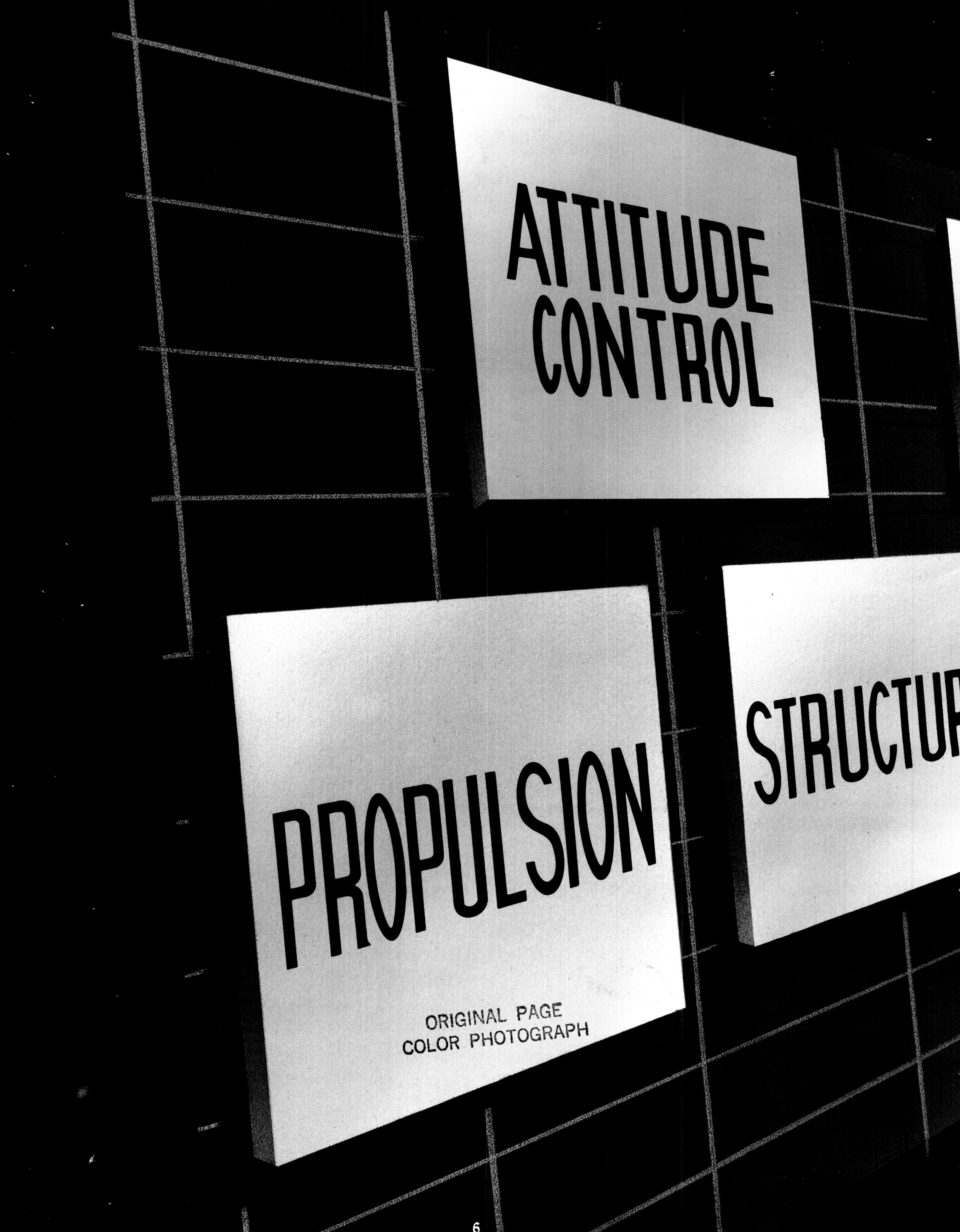
ATTITUDE
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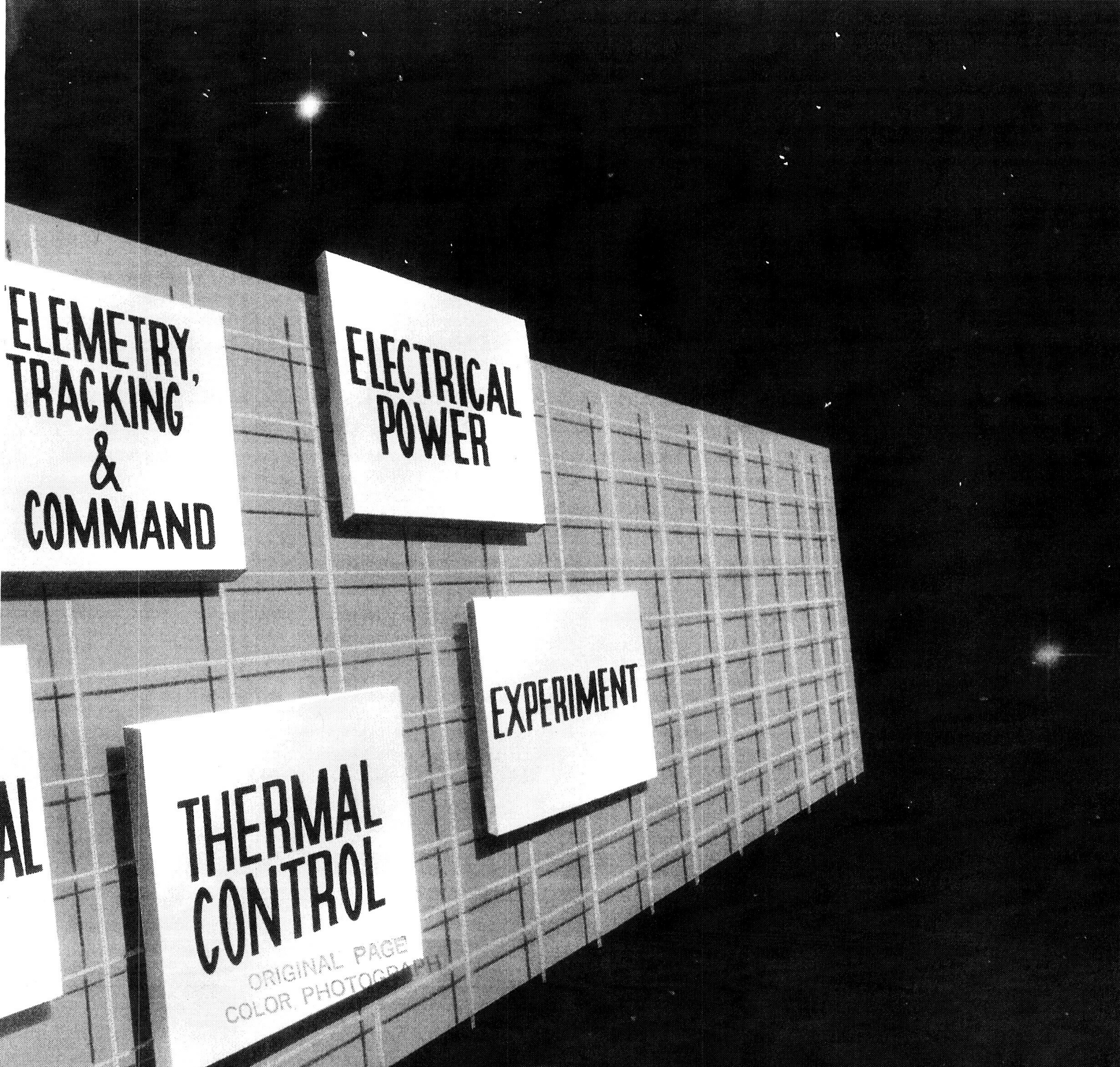
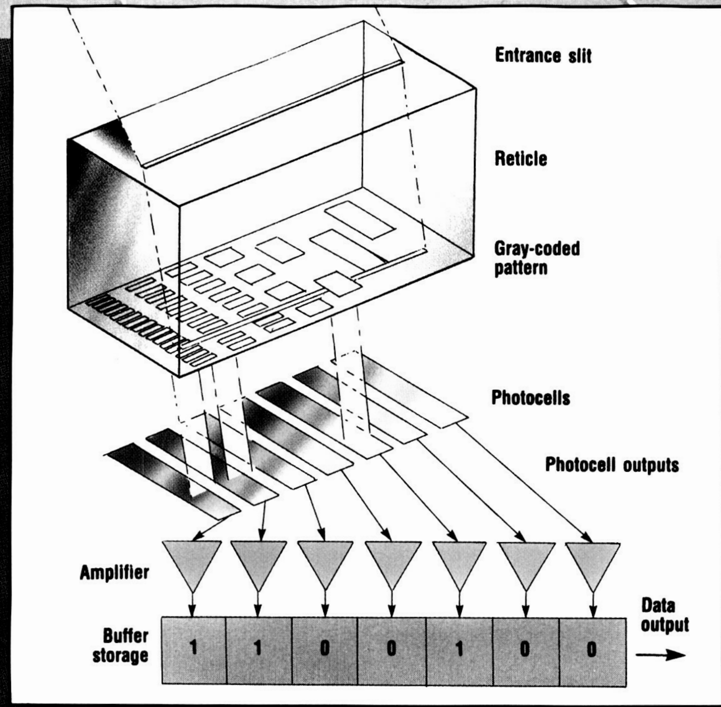



The COLD-SAT spacecraft comprises seven major subsystems: (1) attitude control, (2) propulsion, (3) structural, (4) telemetry, tracking, and command, (5) thermal control, (6) electrical power, and (7) experiment. Each of the subsystems is important in the successful operation of the COLD-SAT. A brief description of the requirements and possible composition of each subsystem follows.

## ATTITUDE CONTROL SUBSYSTEM

The attitude control subsystem will comprise the hardware and software elements necessary for on-orbit attitude control for the spacecraft. Acceleration disturbances to the experiment will be minimized. The computation and logic requirements will be accomplished by a general-purpose, digital computing unit. Sensing functions will be provided by gyros and by sun and horizon sensors. Pointing accuracy will be of the order of $\pm 3°$.




*Typical digital sun sensor*

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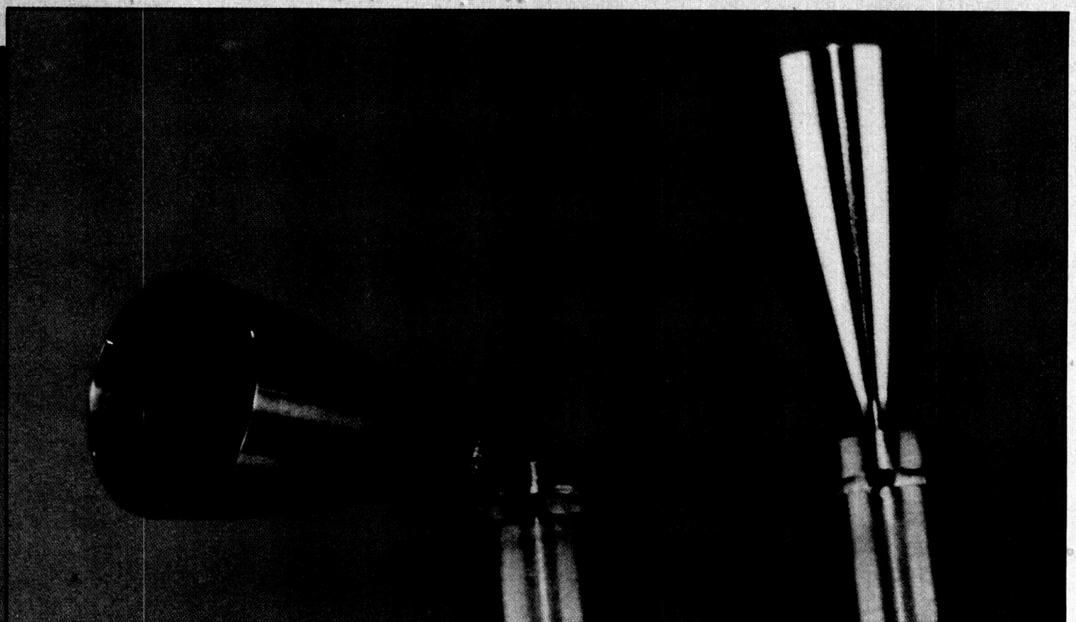
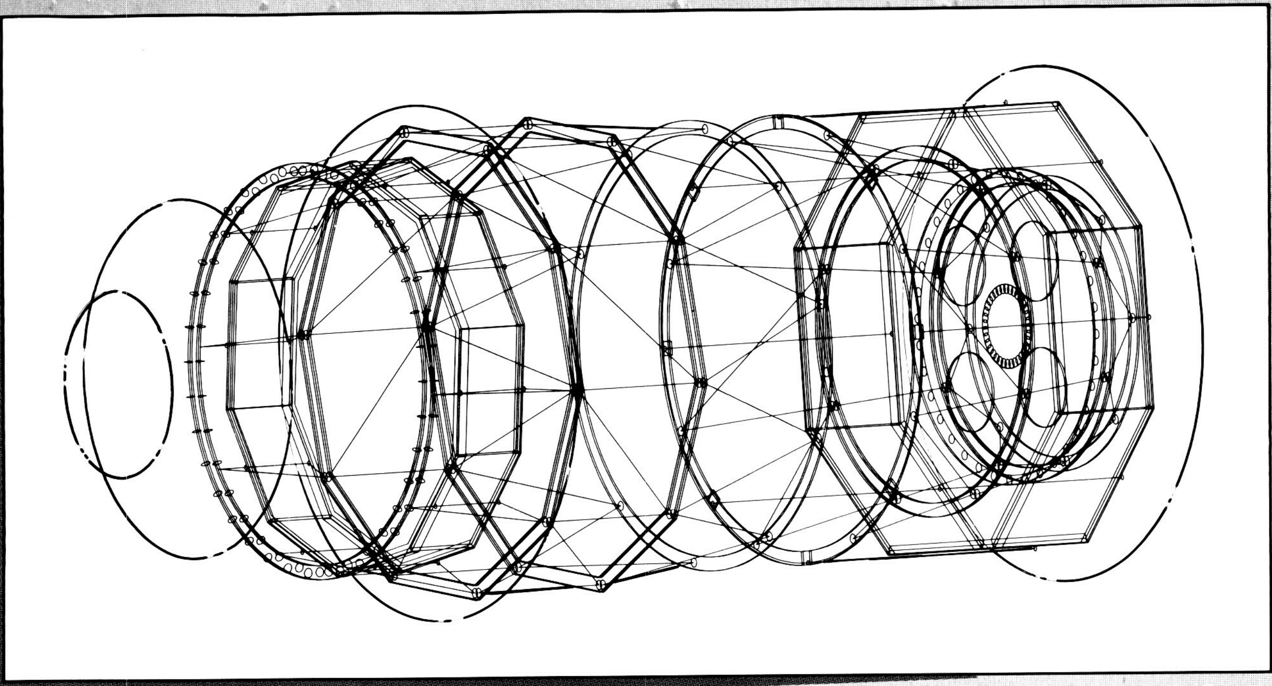


*Hydrazine attitude control thrusters*

## PROPULSION SUBSYSTEM

The propulsion subsystem will provide torques for controlling spacecraft attitude and will provide the required experimental accelerations. A conventional hydrazine propulsion system operated in a modified "blow-down" mode is proposed on COLD-SAT. The configuration will be redundant. Any failure resulting in leakage in the thruster module or feed lines to the thruster module will be isolated by the appropriate feed module isolation valve, thereby permitting full utilization of the available propellant in the redundant half-system.



*A computer-aided design concept of the COLD-SAT structure*

## STRUCTURAL SUBSYSTEM

The COLD-SAT structure will be conservatively designed with high safety factors so that the integrity of the structure can be verified by analysis and static tests. Proven construction techniques and materials with known properties will be used. The structural design will incorporate a combination of longerons, shear panels, rings, and trusses. The structure will be fabricated primarily of aluminum. Additional supports, brackets, lines, and hold-down devices will complete the structural support subsystem.

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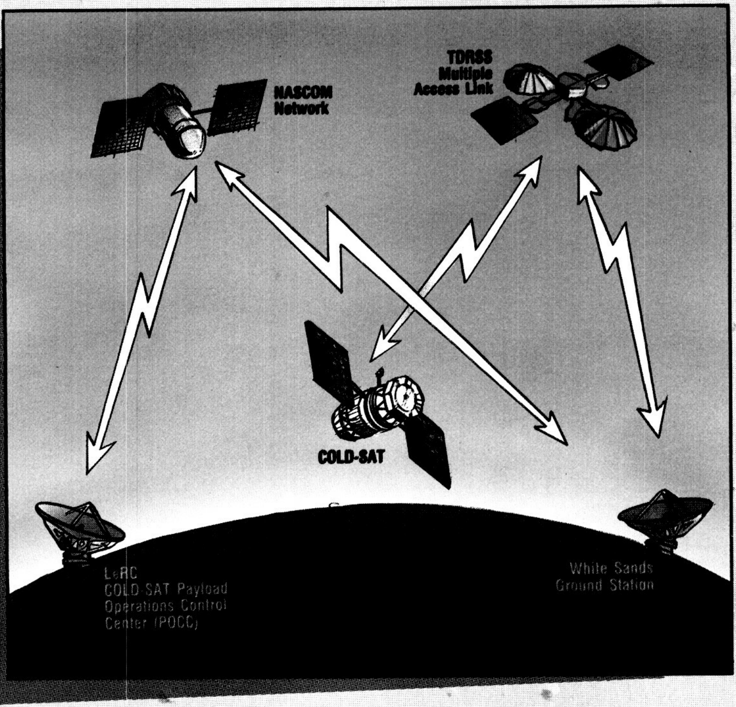
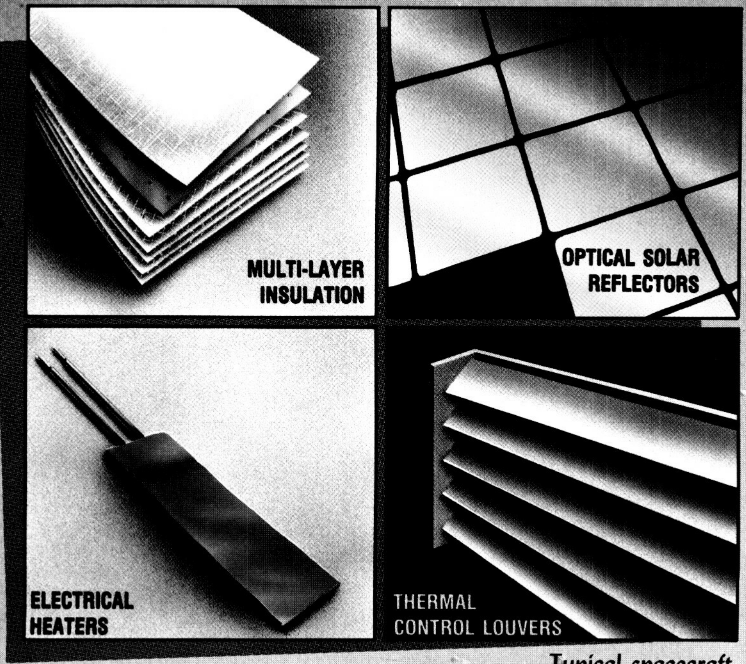



*Spacecraft communication interfaces*

## TELEMETRY, TRACKING, AND COMMAND SUBSYSTEM

This subsystem will authenticate and distribute commands to all experiments and spacecraft subsystems and will be compatible with the unified S-band of the NASA tracking and data relay satellite system (TDRSS). This subsystem will acquire and format scientific and engineering data. The data will be sampled by remote multiplexer units located throughout the spacecraft. The digital computing unit will provide the sequencing control for data sampling, formatting, and transmitting to the storage device and the base band assembly for subcarrier modulation and real-time downlink transmission via the TDRSS.



*Typical spacecraft thermal control devices*

## THERMAL CONTROL SUBSYSTEM

There will be wide variations in the thermal environments for the components within the COLD-SAT spacecraft and in the incident heat fluxes on the outer surfaces from the external environment. Therefore, the thermal control subsystem will be required to achieve temperature control by establishing an appropriate heat balance between absorbed radiation, internal heat dissipation, and emitted energy. Another important goal of this subsystem is to increase the storage life of the cryogen by minimizing the surface temperature of the supply tank to reduce the parasitic heat leak into the tank. Conventional techniques such as multilayer insulation blankets, louvers, and coatings will minimize the effects of large variations in incident radiation caused by changes in the spacecraft orientation. Also, heaters will be used to help maintain temperatures within prescribed limits.

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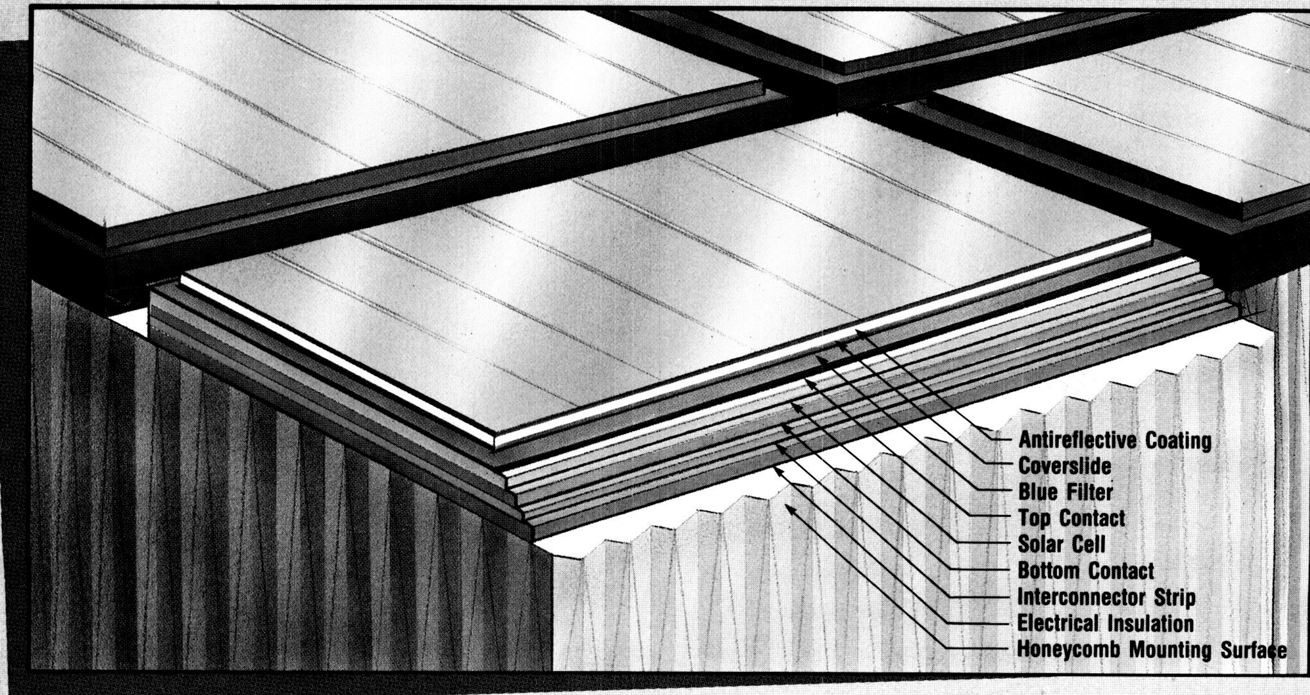

*Conventional solar cell element*

## ELECTRICAL POWER SUBSYSTEM

Components of this system will include solar arrays, rechargeable batteries, a power control unit, and a power distribution unit. The solar arrays will consist of two deployable wings that will supply power to the experiment and spacecraft subsystems during the nominally 62 minutes of daylight for each orbit. The batteries will power COLD-SAT during the approximately 34 minutes of eclipse and will be recharged with solar panel power. The power control unit will provide bus protection circuits, battery charge/discharge control, and coarse voltage regulation. It also will contain an interface with the telemetry, tracking, and command subsystem for data and command. The power distribution unit will separate the power into essential, nonessential, and pulse busses. It will then interface with sequencers in the telemetry, tracking, and command subsystem where individual loads will be actuated.

The electrical power subsystem will supply a nominal 28 volts dc to the spacecraft and experiment subsystems and is capable of supplying an average of 1200 watts of power. The system will be designed to be autonomous, with provision for ground controller intervention. The solar panel and battery charge/discharge functions and the conditioning and distribution functions will be automatic. Software and experiment modules to control power switching will reside in the telemetry, tracking, and command subsystem. Sufficient data will be downlinked to monitor system performance.

*Cutaway of a vacuum-jacketed, liquid hydrogen supply tank*

## EXPERIMENT SUBSYSTEM

The experiment subsystem will consist of a supply tank, two receiver tanks, liquid hydrogen transfer components, pressurant supply, and fill/drain/vent piping and hardware. The supply tank, the largest volume, will consist of an aluminum pressure vessel containing experimental hardware and instrumentation to supply liquid hydrogen to the rest of the experiment. The supply tank will contain a total-communication liquid acquisition device which will make use of surface tension forces to provide a means of expelling gas-free liquid in a low-gravity space environment. The tank will use a thermodynamic vent system as a means of controlling the tank pressure increase due to heat input and will incorporate an internal mixer. Transfer lines with valves and flowmeters will connect the supply tank to the two receiver tanks. Instrumentation to evaluate system performance and to provide for two-phase flow detection and mass flow rate measurements will be available. The supply tank will be launched full and will supply liquid hydrogen to the receiver tanks. The receiver tanks will be thin-walled aluminum vessels containing instrumentation to study the transfer of liquid hydrogen, serving as scaled-down versions of future spacecraft requiring refueling operations.

The fill/drain/vent segment will consist of the valves, fittings, check valves, insulation, heaters, and lines to interface with the ground support equipment. The tank pressurization segment will consist of gaseous pressurant bottles, valves, filters, fittings, regulators, orifices, and lines to supply pressurant to the tanks. The transfer line segment will consist of all devices necessary to study phenomena related to the transfer process. The data acquisition and control segment will consist of all electronics necessary to control experiment processes and to acquire the data relevant to the experiment.

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These subsystems will be designed, fabricated, assembled, and tested by a U.S. aerospace corporation under the direction of the Cryogenic Fluids Technology Office at the NASA Lewis Research Center. Integration of the COLD-SAT spacecraft with the expendable launch vehicle and final verification of the operation of the spacecraft subsystems will be done at the launch site.

The spacecraft will be transported to the launch pad complete with its solar panels and batteries installed, the hydrazine propulsion fuel loaded, the pyrotechnic devices inserted (but unarmed), and the antenna stored in its undeployed position. Final connections between the spacecraft structural support system and the launch vehicle will be made at the launch pad. Checks of the telemetry, tracking, and command subsystem will be made to verify its operational status. Instrumentation in the experiment subsystem will be used to monitor and record the loading of the pressurant and inerting gases.

When the launch day arrives, the final checkout of each subsystem will be made, and the protective nose fairing will be installed to encapsulate the spacecraft. Then the launch pad will be cleared of all personnel, and the liquid hydrogen will be loaded into the supply tank.

During the last two hours prior to liftoff, a final verification of the integrity of COLD-SAT's subsystems will be made from the remote launch control room. With the launch vehicle and spacecraft poised on the launch pad and approvals granted from each of the launch facility operations personnel, the launch director will initiate the liftoff sequence. Telemetry data on the spacecraft subsystems will be recorded as the vehicle ascends. The nose fairing will separate from the spacecraft prior to depletion of the launch vehicle's propellant. In an approximately 500-nautical-mile orbit, the COLD-SAT odyssey will begin.

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15. Supplementary Notes

16. Abstract

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